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Progress Report

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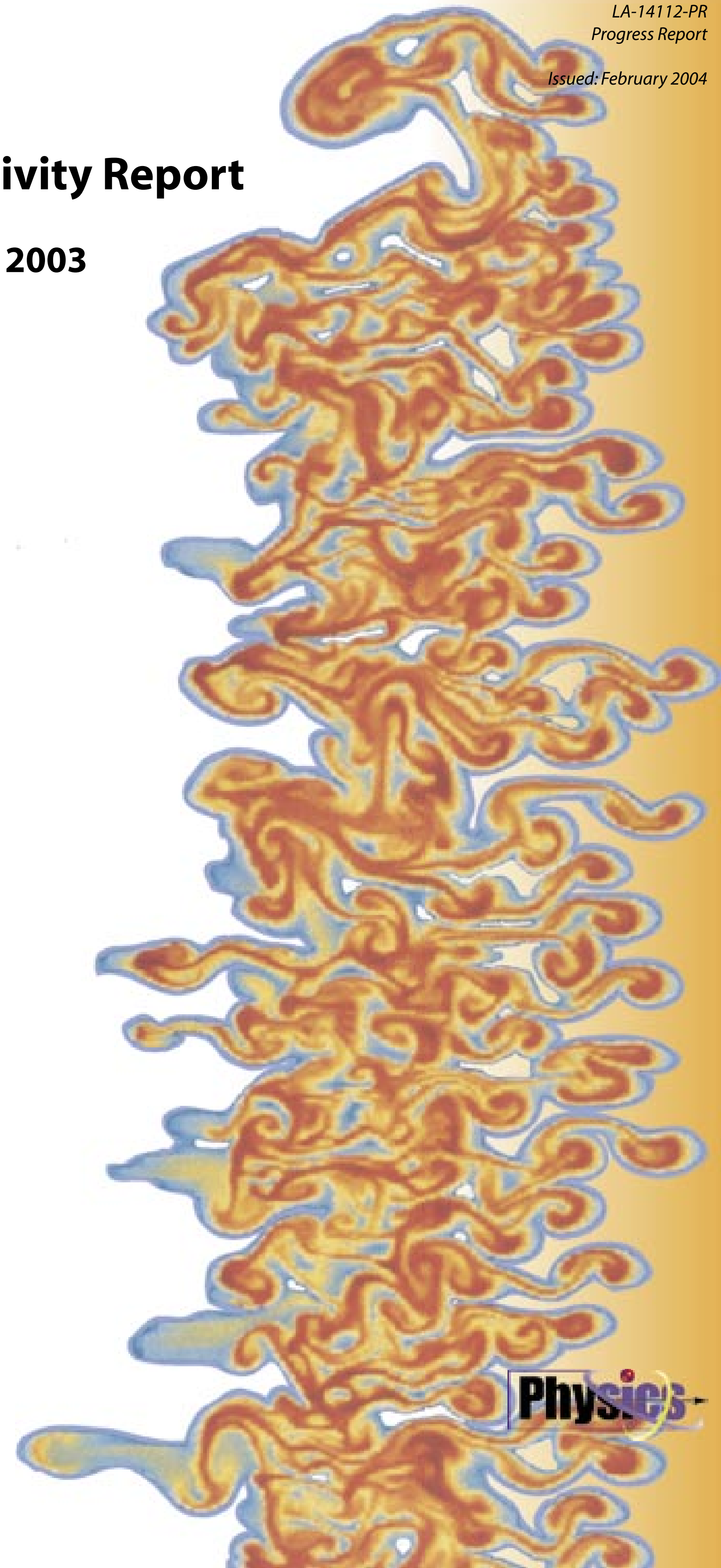
Physics Division Activity Report

January 1–December 31, 2003



1943 - 2003
Los Alamos
NATIONAL LABORATORY
Ideas That Change the World

Physics Division Activity Report

January 1–December 31, 2003

Abstract

This issue of the Physics Division Activity Report describes our activities and achievements in applied and basic science during the calendar year 2003. The report covers the activities of the five Physics Division groups, which represent the main areas in which we serve Los Alamos National Laboratory and the nation: Biological and Quantum Physics, Hydrodynamics and X-ray Physics, Neutron Science and Technology, Plasma Physics, and Subatomic Physics. This report includes a message from the Physics Division Leader, Susan Seestrom; general information about the mission and organization of the Division; our staffing and funding data for the fiscal year; descriptions of the activities of each of our groups; highlights of major research efforts throughout the Division; descriptions of the individual projects that we support; and a list of our publications and conference presentations.

Contents

Division Leader's Introduction

The year 2003 began in great turmoil at Los Alamos National Laboratory (LANL). Our Director and Principal Deputy Director vacated their positions in the midst of public allegations of fraudulent procurement activity on the part of Laboratory employees and alleged attempts by the management to cover up and retaliate against those who were conducting internal investigations. Admiral George "Pete" Nanos was appointed acting Laboratory Director on January 2, 2003, and then appointed permanently in May 2003 by the University of California (UC) Regents. Even though the allegations of procurement fraud proved to be unfounded, the scrutiny applied to LANL in all areas of potential business, safety, or security problems continued throughout the year. We have responded to numerous immediate requirements for data, procedures, and new documents to demonstrate accountability for property, classified media, training, work authorization, foreign visitors, etc. We have some of the very best business and safety staff in our division; they have been indefatigable and tenacious in ensuring our scientists deal with sensible procedures and requirements. Also this year, we completed the very first Facilities Strategic Plan for the Physics (P) Division. We believe this is key to solving the serious problems of poor-quality laboratory space and insufficient office space. It has earned us the possibility of occupancy in a new stockpile stewardship building that will be proposed for congressional-line-item funding in 2004.

Of course, the uncertainty that surrounds the Department of Energy (DOE) contract with the UC affects employees at both a personal and professional level. It is the reputation of the UC that enables us to continue to attract and retain the very best scientists to LANL, and we are concerned that a departure of UC from the management of our science could significantly hinder our ability to perform world-class science and develop state-of-the-art technology. I am extremely proud that in spite of these uncertainties and distractions that our staff continues to be honored with important awards and fellowships; for example, the Laboratory received eight American Physical Society fellowships in 2003—more than any other organization, including UC or other DOE national laboratories.

The broad field of physics continues to be very healthy at LANL. A recent statistical study of publications and citations shows that nearly half of all LANL publications are in the physics field, as are half of the citations. The number of citations for our physics publications places LANL as the eleventh ranked physics department in the country and first among the DOE national laboratories [see E. Ben-Naim, "Los Alamos National Laboratory Publications 1993-2003: A Statistical Study," Los Alamos National Laboratory report LA-UR-03-9087 (2003)].

Despite the distraction of our workforce to attend to the business, safety, and security requirements for conducting the business of science at the Laboratory, P Division scientists continued to produce high-quality scientific work. I am also proud that our Division communications team published the 2003 Activity Report (which describes work performed throughout the Division) so quickly after the new year. This report, like the Physics Division as a whole, is largely organized by physics disciplines, and we continue to lead experiments in areas of importance both for national security and basic science. Under the rubric of materials studies, one of the major strategic goals for the laboratory, P Division researchers continued their tradition of capturing complex, dynamic data in harsh environments on plutonium in subcritical tests. Other research highlights examine the behavior of materials under extreme loading produced by magnetic compression and laser-driven shock waves. Diagnostic development remains a hallmark of the Division, and we have made significant progress in the implementation of both temperature and velocity probes.

Plasma physics remains a core capability of the Division with applications to nuclear-weapons performance, energy production, and astrophysics. Our researchers are involved in sophisticated imaging experiments to study the evolution of turbulent systems and the spatial emission of neutrons from a hot, compressed capsule. Plasma experiments studying radiation flow are described in a research highlight that discusses work performed at the Z facility at Sandia National

Laboratories, and our leadership in magnetized target fusion is highlighted in an article on the LANL FRX-L facility.

Our own in-house laser facility, the Trident laser, provides a diverse set of pulse-shape, energy, and wavelength options in a heavily diagnosed environment, available to both local and outside users, and Trident occupies an important place in P Division's portfolio.

Technology advances have been made in the use of both muons and electrons as radiographic probes. These unique techniques are showcased in a variety of separate research highlights that describe the methods and applications using charged particles for imaging and interrogating objects. Our detector work is at the forefront of the field as exemplified in an article about our gated x-ray framing cameras, and we are applying our nuclear-physics techniques to homeland security issues in the development of the Very Large Area Neutron Detector (VLAND) concept.

Among the most exciting results in the recent past are those obtained through our experiments at the Sudbury Neutrino Observatory, located deep underground in an active nickel mine in Ontario, Canada, where we witnessed new physics in the unambiguous observation of solar-neutrino flavor transformation. We anticipate significant results from a variety of other nuclear-physics experiments over the coming years. Progress towards measurement of the neutron electric dipole moment, neutrino oscillations in accelerator experiments, and parity-violating gamma asymmetry in the NPDGamma experiment are each described separately in highlight articles. Our work on the Pioneering High-Energy Nuclear Interaction Experiment (PHENIX) continues with the Silicon Vertex Tracker project, which will enable the study of charm and beauty quark signals at the Relativistic Heavy Ion Collider. Astrophysical data are being collected at two facilities described in this report, namely the High Resolution Fly's Eye (HiRes) in Utah and our own Milagro Teravolt Gamma Ray Observatory at Fenton Hill.

Susan J. Seestrom, Physics Division Leader

In the Biophysics arena, our scientists have been engaged in neural-circuit modeling as we have extended our understanding of information processing in the vertebrate retina. For several years, we have been improving and applying the most sensitive magnetic sensors yet known, superconducting quantum interference devices (SQUIDs), to the non-invasive study of the electrical activity in the brain. We are now coupling this type of data with that obtained from other tools in work described in a research highlight on the integration of brain information from multiple diagnostic probes.

Three research highlights are categorized as atomic physics because they deal with the uniquely quantum behavior of matter at the atomic scale. The work involves fundamental tests of the random nature of quantum mechanics and application of this randomness to the practical problem of encryption and key distribution. We are also exploring the exciting regime of Bose-Einstein condensates in which large clouds of atoms are governed by quantum mechanics.

I believe these research highlights speak for themselves about the quality of research in P Division. Overall, 2003 was a very eventful year at LANL, yet we remain optimistic that the Laboratory will continue to prove that UC management is sound and accountable so that our research can continue at the high level expected by our leadership, our scientists, and the nation.

Mission and Goals

The mission of Physics (P) Division is to further our understanding of the physical world, to generate new or improved technology in experimental physics, and to establish a physics foundation for current and future Los Alamos National Laboratory (LANL) programs.

The goals of P Division are to

- provide the fundamental physics understanding supporting LANL programs;
- investigate the basic properties of nuclear interactions, high-energy-density and hydrodynamic systems, and biological systems with a view toward identifying technologies applicable to new LANL directions;
- identify and pursue new areas of physics research, especially those to which the unique capabilities of LANL may be applied;
- explore interdisciplinary areas of scientific endeavor to which physical principles and the methods of experimental physics can make an important contribution; and
- maintain strength in those disciplines that support LANL's mission.

P Division pursues its goals by

- establishing and maintaining a scientific environment that promotes creativity, innovation, and technical excellence;
- undertaking research at the forefront of physics with emphasis on long-term goals, high risks, and multidisciplinary approaches;
- fostering dialogue within the Division and the scientific community to realize the synergistic benefits of our diverse research interests;
- encouraging the professional development of each member within the Division; and
- conducting all of its activities in a manner that maintains a safe and healthful workplace and protects the public and the natural environment.

S. J. Seestrom
Division Leader

J. S. Shlachter
Deputy Division Leader

A. P. T. Palounek**
Deputy Division Leader

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Chief of Staff

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A. P. T. Palounek
Advanced Radiography PE Mgr

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Fusion Energy Project Mgr

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P-21: Biological and Quantum Physics

C. C. Wood, *Group Leader*
W. R. Scarlett, *Deputy GL*
S. M. Glick, *Deputy GL*

P-22: Hydrodynamics and X-Ray Physics

D. W. Scudder, *Group Leader*
J. B. Aubrey, *Deputy GL*

P-23: Neutron Science and Technology

R. D. Fulton, *Group Leader*
J. E. Schinkel, *Deputy GL*
B. K. Park, *Deputy GL*

P-24: Plasma Physics

C. W. Barnes, *Group Leader*
C. Munson, *Deputy GL*
M. Ray, *Administrative Deputy GL*

P-25: Subatomic Physics

M. D. Cooper, *Group Leader*
M. B. Johnson, *Deputy GL***
G. B. Mills, *Deputy GL***

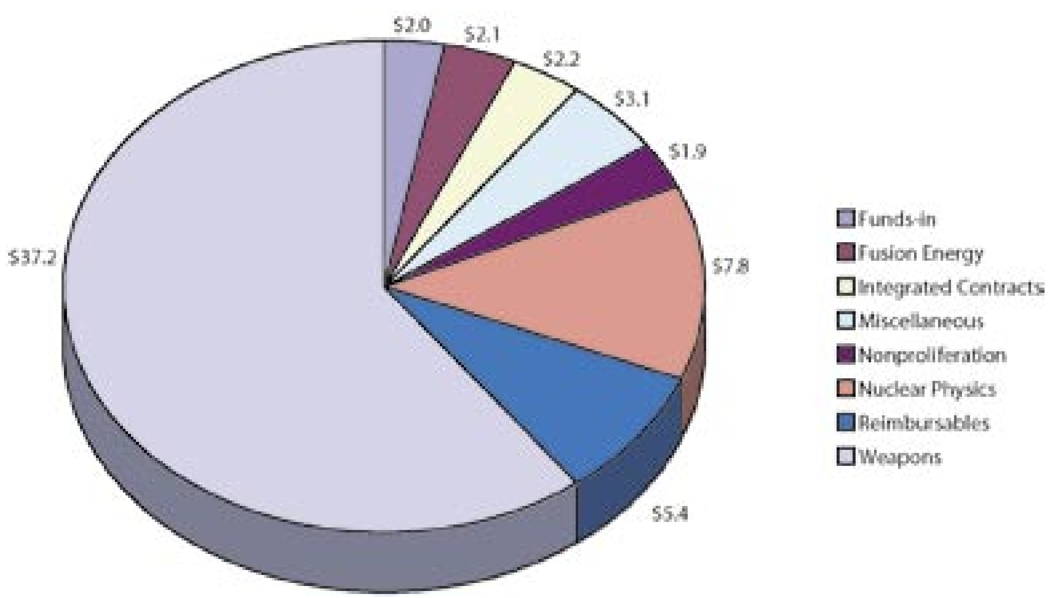
*PE = Program Element
**Acting

Financial Data

Cost and Budget History

	FY00	FY01	FY02	FY03
Direct Operating Costs	48.5	49.4	55.8	61.8
Direct Capital	15.7	3.9	6.1	5.5
LDRD	5.0	7.4	8.1	8.3
Indirect (G&A, Overhead)	17.9	19.7	20.8	17.0
Total Costs	87.1	80.4	90.8	92.6
Total Budget	93.2	90.4	101.0	100.7
Remaining	6.1	10.0	10.2	8.1
FTEs	267	283	295	322

FY 2003 Direct Costs by Funding Source



P-21: Biological and Quantum Physics

Charles Wood,
Group Leader
Robert Scarlett,
Stephen Glick,
Deputy Group Leaders

The Biophysics Group (P-21) was founded in 1988 with the goal of applying the scientific and technical resources of P Division to the biosciences. In October 2002, P-21 broadened its scope to become the Biological and Quantum Physics Group with the addition of the Quantum Information Team from P-23. This organizational change was initiated by P Division leadership for two reasons. First, P-21 has longstanding experience in supporting entrepreneurial projects for non-DOE (Department of Energy) government agencies such as the National Institutes of Health (NIH), the Department of Defense (DOD), and the intelligence community, many of which are key sponsors for work in quantum information. Second, the Quantum Team and the Biophysics Group share common interests in the *Physics of Information* at all levels, from quantum information processing, computing, and cryptography to biological information processing by the nervous system. This common focus on the basic science and applications of information processing has already led to numerous constructive interactions between the biological and quantum components of P-21.

Biological Physics

P-21's historical mission has been to contribute to an understanding of biological phenomena by means of the scientific, technical, and conceptual resources of physics; to use biological systems to elucidate general physical principles underlying complex phenomena; and to apply, where appropriate, our scientific and technical capabilities to core LANL programs. Just as the 20th century is regarded as the century of the physical sciences, the 21st century will likely become the century of the biological sciences. P-21 and biophysics as a discipline are well positioned to contribute to this biological *revolution in progress* through our emphasis on understanding biological systems using the scientific, technical, and conceptual resources of physics. Recent advances in biophysical measurement and in molecular biology are beginning to allow detailed physical understanding of biological phenomena that were previously understood only in qualitative terms. P-21 is well placed by virtue of its capabilities and research interests to contribute significantly to this important trend in the biosciences. In addition to the goal of achieving a physical understanding of biological phenomena, the biophysical research in P-21 shares a number of other common characteristics. Specifically, we investigate the relationships between structure, dynamics, and function of biological phenomena over a wide range of scales (e.g., from biomolecules to the whole human brain). We also make extensive use of detection, imaging, and reconstruction techniques [(e.g., x-ray crystallography, single-molecule electrophoresis, high-speed photon-counting optical imaging, magnetic resonance imaging (MRI), and magnetic-field measurements using technologies based on superconducting quantum interference devices (SQUIDs)]. Moreover, we attempt to achieve a detailed interplay between high-resolution physical measurements and large-scale computational modeling and analysis of complex systems, and we develop new facilities in support of our scientific and technical goals, including the following:

- a dedicated x-ray beam line for protein crystallography at the National Synchrotron Light Source (NSLS) at Brookhaven National Laboratory

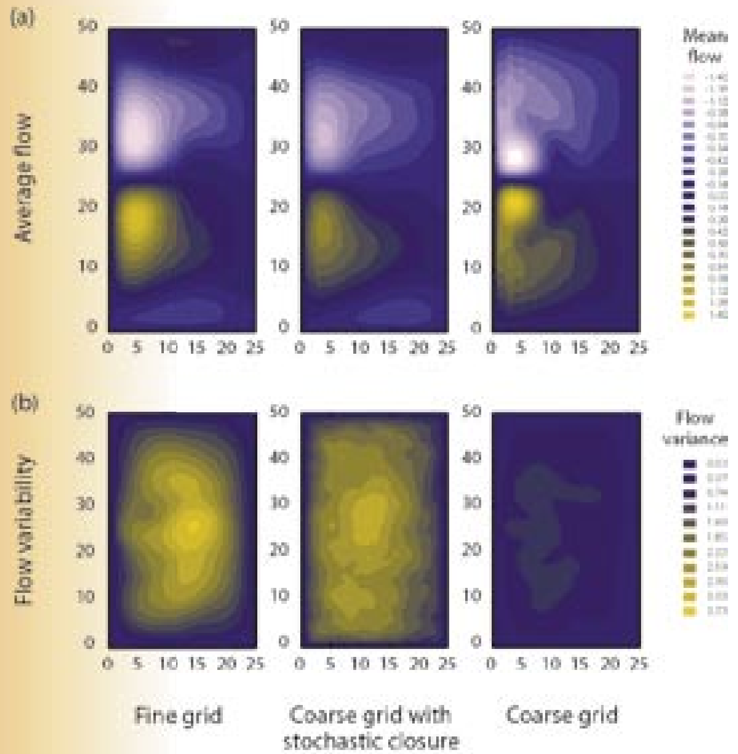


Figure 1. P-21 has developed a new probabilistic approach to the problem of "closure" in large-scale numerical models that require spatial grids. Based on ideas originally developed in the context of P-21's work on brain imaging, this "stochastic closure" approach uses probabilistic methods to make substantial improvements in a model's ability to estimate both average quantities (a) and measures of variability (b) compared to conventional closure approaches. This work is supported by a LANL LDRD-DR project (David M. Schmidt, P-21, Principal Investigator) that involves applications of stochastic closure in biomedical imaging, ocean modeling, flow in porous media, and weapons hydrodynamics.

(BNL)—which we are in the process of handing over to our consortium partners, the Canadian National Research Council, Roche Pharmaceuticals, and BNL Biology;

- a multi-modality imaging facility that includes a large-bore MRI capability, a whole-head magnetoencephalography (MEG) system, whole-head electroencephalography (EEG) arrays, and optical imaging and tomography;
- a high-speed, time-domain measurements and electronics laboratory and fabrication facility; and
- a growing SQUID applications laboratory.

We depend heavily on the tight connection and daily interplay between biologists and physical scientists within the group, the Division, and the Laboratory, and we apply the knowledge, techniques, and capabilities developed in our biological studies to problems of national security and those of specific interest to LANL when our ongoing efforts can offer unique solutions and significant mutual benefit. For example, P-21 has developed a new approach to the problem of "closure" in large-scale numerical models based on partial differential equations (Figure 1). This work is the focus of a Laboratory-Directed Research and Development-Director's Reserve (LDRD-DR) funded project involving members of the ocean-, flow-, and weapons-modeling communities.

Quantum Information Science

A key discovery of twentieth century science was the realization that information is physical. The representation of "bits" of information by classical physical quantities, such as the voltage levels in a microprocessor, is familiar to everyone and is the basis of the "information explosion" of the latter half of the twentieth century. More recently, the field of quantum information science has made great progress in understanding information in terms of the laws of quantum mechanics. For example, a unit of quantum information, known as a "qubit," can be represented by single-photon polarization states. Remarkable new capabilities in the world of information security have been predicted that make use of quantum-mechanical superpositions of information, a concept that has no counterpart in conventional information science. For example, quantum cryptography allows two parties to communicate securely even in the presence of hostile monitoring by a third party (as described below). P-21's Quantum Information Team has experimental projects under way in quantum cryptography, in quantum computation, in quantum optics with trapped strontium ions, and atom interferometry with Bose-Einstein condensates.

Quantum cryptography. One of the main goals of cryptography is for two parties ("Alice" and "Bob") to render their (binary) communications unintelligible to a third party ("Eve"). This can be accomplished if Alice and Bob both possess a secret random-bit sequence, known as a cryptographic key. For example, in "one-time-pad" encryption, Alice adds the key to the original message, known as plaintext, and communicates the sum (ciphertext) to Bob. He is able to recover the plaintext by subtracting his key from the ciphertext, but Eve, who is assumed to have monitored the transmitted ciphertext, is unable to discern the underlying plaintext through the randomization introduced with Alice's key. So, although key material conveys no useful information in itself, it is a very valuable commodity, and methods for Alice and Bob to generate key material securely are correspondingly important. Using quantum key distribution (QKD), Alice and Bob can create shared cryptographic key material whose security is ensured by the laws of quantum mechanics.

QKD offers many security and ease-of-use advantages over existing key-distribution methods. Traditional key distribution using trusted couriers requires cumbersome security procedures for preparing, transporting, and handling the key before any communications can take place and may even be impractical (e.g., re-keying a satellite). In contrast, quantum keys do not exist before the QKD transmissions are made, and a key can be generated at message-transmission time. Public-key cryptography also avoids many of the difficulties of key distribution by courier but provides only the conditional security of intractable mathematical problems, such as integer factorization. Accurate assessment of an adversary's computing power over the useful lifetime of encrypted information, which may be measured in years or even decades, is notoriously difficult—unanticipated advances in fields such as quantum computation could render public key methods not just insecure in the future but also retroactively vulnerable. QKD could be used for real-time key generation in cryptographic applications where this long-term risk is unacceptable. Recent progress in QKD is described in a research highlight in this report.

P-21's Quantum Information Team leads the world in many aspects of quantum cryptography. We have demonstrated all aspects of quantum key exchange over 48 km of fiber at LANL and are leading a demonstration of these capabilities over an existing fiber network for the U.S. government. Free-space quantum cryptography was invented by our team, and we have now fully demonstrated the practicality of this approach for a variety of applications over a 10-km range (Figure 2).

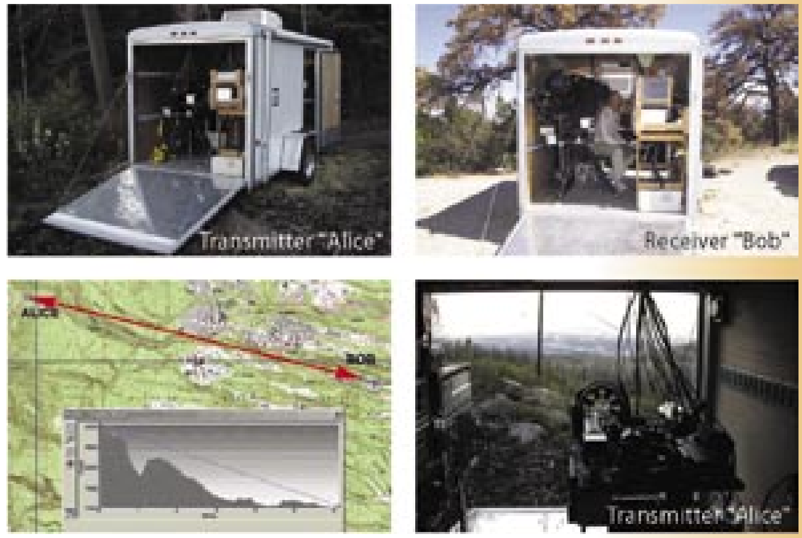


Figure 2. P-21 and collaborators have developed techniques for free-space QKD for which they received a 2001 R&D 100 Award. Shown here are the portable transmitter ("Alice") and receiver ("Bob") used in a free-space QKD experiment over 10 km between Pajarito Mountain and LANL Technical Area 53 (map at bottom left).

Quantum computation. With two or more qubits, it becomes possible to consider quantum logical-"gate" operations in which a controlled interaction between qubits produces a (coherent) change in the state of one qubit that is contingent upon the state of another. These gate operations are the building blocks of a quantum computer, which in principle is a very much more powerful device than any classical computer because the superposition principle allows an extraordinarily large number of computations to be performed simultaneously. In 1994, it was shown that this "quantum parallelism" could be used to efficiently find the prime factors of composite integers. Integer factorization and related problems that are computationally intractable with conventional computers are the basis for the security of modern public-key cryptosystems. However, a quantum computer running at desktop-PC speeds could break the keys of these cryptosystems in only seconds (as opposed to the months or years required with conventional computers). This single result has turned quantum computation from a strictly academic exercise into a subject whose practical feasibility must be urgently determined. The architecture of a quantum computer is conceptually very similar to a conventional computer—multiqubit, or "multibit," registers are used to input data. The contents of the registers undergo logical-gate operations to effect the desired computation under the control of an algorithm, and a result must be read out as the contents of a register.

Many areas of the fundamental science underpinning quantum computation have not yet been thoroughly studied. The P-21 Quantum Information Team is actively engaged in several of these areas. For example, we are using trapped ions to measure the randomness of atomic transitions, which constitute a key test of the predictions of quantum mechanics. Other studies involve ultra-cold atoms collapsed into a Bose-Einstein condensate. These experiments, more fully described in other parts of this report, contribute to the worldwide goal of a complete understanding of this forefront of physical science.

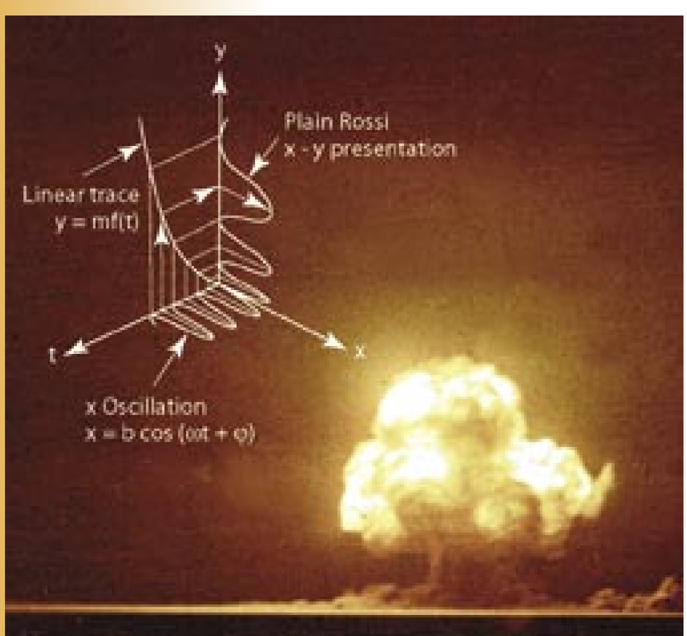
P-22: Hydrodynamics and X-ray Physics

David Scudder,
Group Leader
Joysree Aubrey,
Deputy Group Leader

The activities of the Hydrodynamics and X-ray Physics Group (P-22) help to support LANL's mission of ensuring the safety and reliability of the nation's nuclear stockpile. Group members are also involved in research that addresses fundamental issues related to hydrodynamic phenomena at extreme pressures, high energy-density plasmas, and fusion physics. Other endeavors have led to innovations with commercial potential.

The tremendous challenge of certifying the stockpile in the absence of testing requires that we marshal all the capabilities and resources at our disposal. As the materials in nuclear weapons age, they are removed further and further from the states under which they were tested. Defects in devices and engineering modifications have introduced uncertainties in performance and reliability. To address these issues, we must have a fundamental understanding of the physical processes involved in the performances of nuclear weapons and the limits of models developed and benchmarked during the testing era. P-22 contributes to this challenge in a number of ways through the re-analysis and re-evaluation of archival NTS data in support of stockpile stewardship activities and validation of weapons design codes, diagnostic development and training to enhance the test readiness posture of the nation, and the execution of above-ground experiments with the aim of understanding and resolving weapons physics issues. The group has the resources to assemble multi-disciplinary teams to address these challenges. Our involvement with various experimental programs has required efforts in diverse areas such as optics, hydrodynamics, plasma physics, radiation transport, pulsed-power science, weapons physics, x-ray spectroscopy and imaging, microwaves, electro-magnetics, and nuclear and atomic physics. A number of the projects described below are featured in more detail in this report.

Figure 1. Archival photo of the Trinity event (July 16, 1945). The inset is a schematic representation of the Rossi technique.



NTS data and weapons physics. The first alpha (neutron multiplication rate) measurement was performed by Bruno Rossi on the Trinity event (Figure 1). This diagnostic became a standard tool for assessing the nuclear and thermonuclear performances of devices fielded at the Nevada Test Site (NTS) and elsewhere.

Neutrons in a supercritical assembly increase exponentially according to the formula $N(t) = N_0e^{\alpha t}$. If α is not a constant, then the equation is modified to $N(t) = N_0e^{\int \alpha(t)\, dt}$. The time-dependent neutron population is proportional to the resulting leakage gamma radiation from the surface of the device. The exponentially increasing gamma flux is converted to an electrical current by a series of detectors that span the dynamic range of the signal. The electrical signal in turn is recorded on oscilloscopes driven by oscillators at appropriate frequencies. The Rossi technique consists of the superposition of the exponentially increasing signal on a sinusoidal trace (inset in Figure 1). The time-dependent behavior of the gamma radiation can be extracted by using the known frequency of the sine wave. P-22 is the custodian of archival data from the NTS and is in the process of developing modern methods of analysis and applying them to nuclear events. In collaboration with our colleagues from D-1, ESA-WR, and T-13, we are developing rigorous methods of error analysis for the data in order to deliver higher-fidelity information to the nuclear weapons design and code development community. The re-analysis effort has given us new insights into the physics of individual devices and weapons systems.

High-energy density hydrodynamics (HEDH). Members of the group have done pioneering work in developing and applying pulsed-power facilities to explore hydrodynamic phenomena at extreme pressures and convergent geometries. Under the HEDH program, experiments were conducted to address issues related to LANL's main mission of supporting the nuclear stockpile in the absence of testing. The 4.6-MJ Pegasus II and the 23-MJ Atlas facilities were used to study dynamic material properties under extreme conditions. Experiments included studies of convergent material flow in asymmetric geometries. The data were used to validate models in modern weapons design codes. Other experiments looked at the growth of preformed perturbations during implosions, strength at high strain rates, frictional forces between materials with differential velocities, and spall in materials driven by 50-kbar convergent shocks. The future of the LANL pulsed-power program is full of challenges and exciting new opportunities. The Atlas facility has been moved to the NTS and will be re-commissioned during the spring of 2004. In addition to conducting experiments on the pulsed-power facilities at LANL, P-22 group members have had a long collaboration with scientists at the All-Russian Scientific Research Institute of Experimental Physics at Arzamas-16 (VNIIEF). The Russians have developed large-scale explosive pulsed-power facilities capable of generating fields of thousands of tesla. Joint experiments have explored instability growth in convergent geometries, magnetized target fusion, the design and development of a megajoule x-ray source, and the properties of materials in high fields and at cryogenic temperatures.

In collaboration with DX and X Divisions, we are actively involved in stockpile-related hydrodynamic experiments on the PHERMEX (Pulsed High-Energy Radiographic Machine Emitting X-rays) facility. We have fielded and analyzed high-fidelity, four-frame radiographs for a series of shots. In addition, we have contributed to the effort to bring the second axis of the Dual Axis Radiographic Hydrotest (DARHT) facility on-line. This work included experiments to explore beam-target interactions, development of a pulse coil for DARHT, and the fielding of an electron spectrometer and analysis of the resulting data. The beam-target interaction studies are being conducted in collaboration with DX-6 using DARHT-I as part of a "risk-mitigation" effort for DARHT-II operation. We have also collaborated with DX Division on the scientific and engineering activities related to the Dynamic Experiment (DynEx) program. A series of experiments to measure containment vessel oscillations using microwave interferometry was performed. The objective of these experiments was to determine the radial wall displacement of a 6-ft-diam containment vessel during detonations of different amounts of high explosives. The resulting data were used with other diagnostic data to validate models of vessel behavior.

P-22 plays a very active part in the LANL proton radiography (pRad) program by providing VISAR (velocity interferometer system for any reflector) measurements for dynamic experiments. These experiments include studies of spall and evolution of surface features. The ability to record the details of velocity structure during an experiment is very important for understanding the physics of dynamic processes. The combination of multiple radiographic images and spatially distributed VISAR data from the same experiment provides theorists with high-quality data for benchmarking materials models. Detailed continuous velocity measurements between images contribute to the overall understanding of dynamic processes.

In support of the Dynamic Materials Campaign, we have conducted research in collaboration with DX-2 and P-23 on the production of ejecta from the surfaces of shocked materials and subsequent transport of the particles into gas. These experiments were performed on tin targets at the LANL gas gun facilities. Detailed information about the densities and velocities of particle clouds generated from shocked surfaces

Group Description

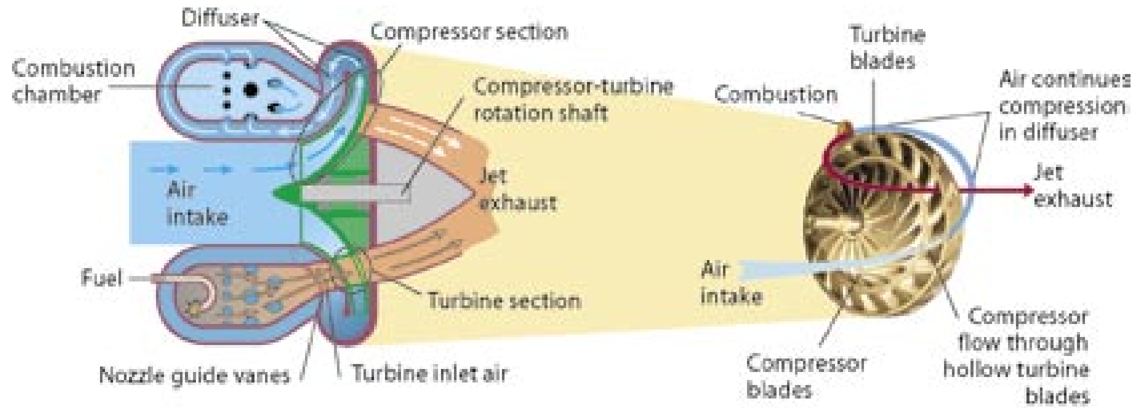


Figure 2. Composite drawing of the ASRT schematic and photo, showing how the ASRT operates. Air from the compressor section of the ASRT is channeled through the outer hollow turbine blades on the same rotor. The air, on its way to the combustion chamber, cools the turbine section allowing the engine to operate at higher temperatures. The fuel efficiency is increased in this case.

is necessary for the development of models of the phenomenon. Another series of experiments is being conducted (in partnership with DX-2) to investigate the behavior of shocked materials off the principal Hugoniot curve. The resulting data provide information about the target material equation of state (EOS) under pressure and temperature conditions that are not easily accessible by other means. In collaboration with P-23, DX-2, and MST-7, P-22 staff used optical pyrometry to measure the temperature of shocked materials to elicit information about solid-solid and solid-liquid phase transitions. Such information has been very valuable in testing EOS models of materials

Strongly coupled plasmas and radiation hydrodynamics. The understanding of the properties of strongly coupled plasmas and the interaction of these plasmas with radiation is important for fusion and weapons physics applications. We are involved in various research projects in these areas using both local facilities and those elsewhere, such as the Z machine at Sandia National Laboratories (SNL) and the Omega laser at the University of Rochester. We are conducting investigations of fundamental processes that are relevant to fusion and strongly coupled, multi-material plasmas. The work is being done locally under an LDRD project and involves two experiments aimed at measuring the ion-ion diffusion coefficient and the temperature equilibration rate between ions and electrons in a dense plasma. We have also studied the propagation of radiation in materials using the x-ray source generated by SNL's Z machine, which generates currents of 20 MA and a peak electrical power of about 40 TW. This source has been used to study the physics of radiation-matter interactions.

New initiatives. Members of P-22 are developing methods of encoding information to deliver digital television images using the existing analog NTSC (National Television System Committee) format. The data for high-definition TV (HDTV) can be viewed by analog TV receivers. No hardware modifications are required for the old monitors or the new high-definition sets. The information for the digital images (quantized coefficients in the transform space) is transmitted by modulating the carrier in a novel way. A second innovation developed by a group member, the Advanced, Single-Rotor Turbine (ASRT) (Figure 2), was recently nominated for an R&D 100 Award. The compressor and turbine are combined into a single piece, increasing reliability while reducing engine complexity and size, as well as fabrication and maintenance cost. Envisioned applications for this technology include portable power units and residential distributed power supplies, as well as small jet engines and turbo-shaft engines for turboprop aircraft, helicopters, and tanks. Centrifugal turbines could also be implemented in turbo-chargers for piston engines and turbo-pumps for liquid-fueled rockets, refrigeration, and applications in the chemical-processing industry.

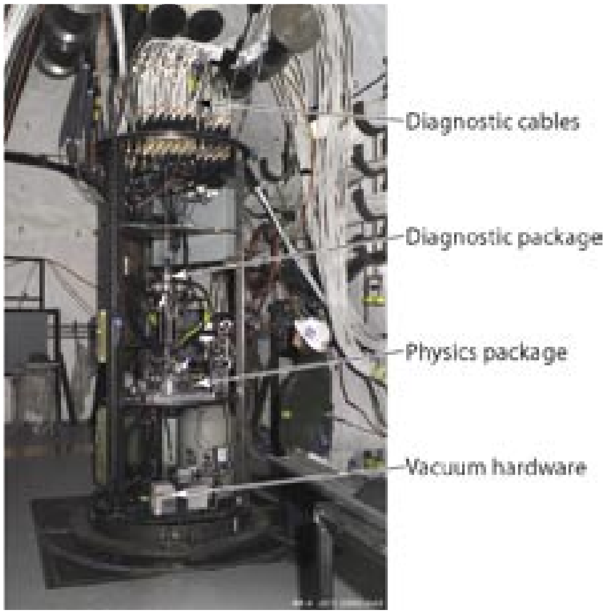
P-23: Neutron Science and Technology

Doug Fulton,
Group Leader
Jeffrey Schinkel, Brent Park,
Deputy Group Leaders

The Neutron Science and Technology Group (P-23) executes a wide range of projects spanning weapons physics and nuclear physics through fundamental and applied research. The core capabilities of the group are in the application of state-of-the-art techniques in particle and light detection and in the recording of transient events. Our efforts in weapons physics contribute to the national security mission of LANL through the stockpile stewardship program by participating in the design and fielding of subcritical experiments (SCEs), small-scale dynamic experiments, and the reanalysis and archiving of data from past nuclear weapons tests. Our fundamental research contributes to science in support of LANL programs through studies on nuclear and weak-interaction physics and on state-of-the-art measurements of astrophysical phenomena such as solar neutrinos and ultra-high-energy gamma rays. Applied research includes the application of imaging and neutron technologies to problems relevant to national defense, homeland security, and industry. A number of the projects and programs described below are featured in this report.

Weapons physics. Members of P-23, working in collaboration with P-22 and various groups in DX, ESA, X, NMT, and MST Divisions, designed and executed the Stallion series (Vito, Mario, Rocco, and Armando) of SCEs. The purpose of Vito was to examine ejecta formation in a particular region of a weapon, and it successfully demonstrated the LANL "racklet" technique that facilitates rapid and cost-effective turnaround between SCEs (Figure 1). The racklet method was subsequently employed for Mario and Rocco. The purpose of Mario and Rocco (and soon Armando) was to compare the properties of cast versus wrought plutonium.

Figure 1. The racklet assembly before it was lowered into the confinement hole was successfully demonstrated on the Vito SCE.



The specific properties investigated in SCEs include ejecta formation, spall features, and surface temperature. Holography, used to measure ejecta-particle-size distributions, provides information about ejecta-particle transport in a gas environment. Another method, soft x-ray imaging, was developed to measure ejecta-density distributions from shock-loaded metals, and pRad was used for the first time to study material failure in depleted uranium and other materials. Surface temperature is measured with a high-speed, time-resolved, multi-wavelength near-infrared surface pyrometer. All these methods provide data that contribute to our understanding of the strength, failure properties, and EOS of materials important to the weapons program. Another EOS constraint can be obtained from volume temperatures. Neutron resonance spectroscopy (NRS) determines volume temperatures by using Doppler-broadened neutron resonances to measure internal temperatures in dynamically loaded samples. Although still a nascent technique, our researchers plan on using NRS to measure the temperatures attained in shocked metals, at frictional interfaces, and in the "dead zones" of detonated chemical explosives.

P-23 also supports pRad and other facilities and capabilities such as DARHT by developing and fielding imaging systems and advanced detector systems. Historically, P-23 has been the locus for advanced imaging technologies developed to meet the demands of the weapons program. Our imaging expertise is currently being applied to inertial-confinement-fusion (ICF) experiments via neutron pinhole imaging. This simple yet powerful technique allows us to capture neutron images of capsules used in ICF experiments and thus contributes to improvements in capsule design. However, the application to ICF requires pinhole dimensions that push the limits for fabrication and fielding. In 2003, new milestones in pinhole fabrication were met, resulting in the highest resolution images recorded to date, as well as the first "double-aperture" image. We continue to investigate different technologies that will provide needed infrared cameras and pixilated detector technology for pRad, hydrodynamic experiments, and SCEs.

We also continue to preserve, analyze, and document the NTS and Pacific Ocean weapons test data to gain an understanding of how nuclear weapons systems perform. P-23 analyzes imaging data from the pinhole neutron experiments (PINEX) and neutron-emission measurements from neutron experiments (NUEX) and threshold experiments (THREX). The physicists and engineers who performed the original measurements are correlating and reanalyzing the data from different events, using new methodologies and improved analytical techniques. Our aim is to develop better physics models and provide certified NTS data that will allow validation of the Advanced Strategic Computing Initiative (ASCI)—an important goal of the stockpile stewardship program.

Nuclear physics and astrophysics. The neutrino research effort in P-23 has focused on our continuing role in the Sudbury Neutrino Observatory (SNO) in Ontario, Canada (Figure 2). SNO is searching for three interactions of solar neutrinos: the charged-current, the neutral-current, and the elastic-scattering interactions. Recent results indicated a total neutrino-flux measurement in good agreement with predictions of the Standard Solar Model (SSM). The detection of muon and/or tau neutrinos through neutral current interactions in SNO supports flavor transformation that accounts for the electron neutrino deficit. A second avenue of research into neutrinos is the Majorana experiment that aims to characterize the nature of the neutrino, its mass spectrum, and the absolute mass scale.

A broad and ambitious set of neutron-research projects involves colleagues in P-25 and a host of collaborating universities and institutions. Two of these projects—the NPDGamma ($n + p \rightarrow d + \gamma$) and ultra-cold neutron (UCN) experiments—will soon be commissioned. The NPDGamma experiment will help researchers better understand the nature of weak interactions between strongly interacting hadrons by measuring the parity-violating directional gamma-ray asymmetry to an accuracy of 5×10^{-9}, i.e., to within approximately 10% of its predicted value. This project has involved the design, construction, and commissioning of a pulsed, cold-neutron beam line along flight path 12 (FP12) at the Lujan Neutron Scattering Center (Lujan Center) at the Los Alamos Neutron Science Center (LANSCE). FP12 will also be used, upon completion of the NPDGamma experiment, to measure the electric dipole moment (EDM) of the neutron. The goal of the EDM project is to achieve over two orders of magnitude improvement to the limit of the EDM by using UCNs (produced and stored in a bath of superfluid ^{4}He) and SQUIDs to monitor ^{3}He precession. FP12 may also be used to measure pulsed-cold neutron beta decay as a test of the Standard Model of electroweak interactions. This experiment incorporates an existing ^{3}He spin-filter neutron polarizer and a new large-area spectrometer that are expected to reduce systematic errors to less than 0.1%. Data acquisition for these projects, as for weapons physics (above), has typically driven improvements in detector capability—a hallmark of P-23. We are also collaborators on the Q_{weak} experiment, which will be conducted at the Thomas Jefferson National Accelerator Facility. This experiment will measure the weak charge of the proton in a test of the Standard Model. To do so will require the use of current-mode detection and low-noise, front-end electronics—two areas of our expertise.

P-23 is conducting an equally ambitious program of astrophysics research through its Milagro Observatory located in the Jemez Mountains above

Los Alamos, New Mexico, and by its participation in the High Resolution Fly's Eye (HiRes) experiment located in Utah. Milagro is the first detector of its kind—a large, water Cerenkov extensive-air-shower (EAS) detector—that can monitor the entire overhead sky in the TeV-energy regime. Since its inception, Milagro has successfully detected the Crab Nebula with flux measurements that agree with values obtained using air Cerenkov telescopes. Building on this work, Milagro subsequently was used to produce a TeV gamma-ray map for the entire northern hemisphere. The HiRes experiment looks for cosmic rays of energy greater than 10^{20} eV. HiRes detects the EASs that result from an ultra-high-energy cosmic ray (UHECR) entering the atmosphere using two independent sites (12.6 km apart) to stereoscopically view the fluorescence caused by an event. A third experiment is the Wide-Angle Cerenkov Telescope (WACT) that employs an array of six atmospheric Cerenkov telescopes. WACT measures the lateral distribution of Cerenkov light created by EASs, allowing inference of the nuclear species of the primary cosmic ray. We have also re-examined archival data collected by the Burst and Transient Source Experiment (BATSE) and Energetic Gamma Ray Experiment Telescope (EGRET) satellites to discover a new high-energy component in one of the 24 gamma-ray burst emissions.

Finally, we have recently developed two experimental plans to search for a time variation of the fine-structure constant, alpha. The first plan involves comparison of three atomic optical frequency standards based on ion traps. The second plan involves a dysprosium-atomic-beam apparatus that will enable radio-frequency (rf) spectroscopy rather than optical-frequency metrology.

Our mission has been to solve challenging experimental-physics problems relevant to our national security—aiming to reduce the threat of war by helping to ensure the reliability of our nuclear-weapons stockpile and by limiting the proliferation of weapons of mass destruction. We anticipate many exciting developments in the coming years, including experiments to measure the time variation of the fine-structure constant, new studies into the nonlinear interaction of ultra-short laser pulses with structured fibers, a series of new SCEs at the NTS to be conducted in collaboration with the United Kingdom, and a proposed experiment (Majorana) to measure the fundamental character of the neutrino via double beta decay.

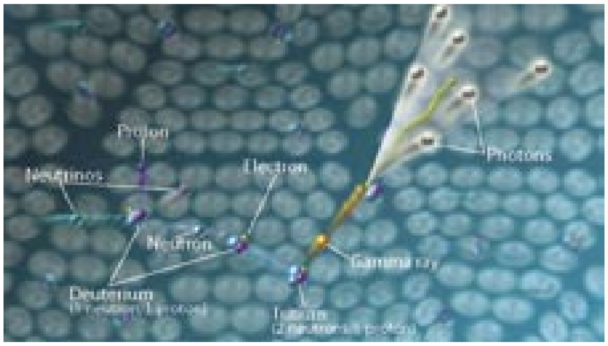


Figure 2. Rendering of the physics inside the SNO, showing one of three neutrino reactions detected by SNO. A neutrino entering the detector interacts with a deuterium nucleus. The reaction produces a proton, neutrino, and neutron. The neutron is captured by another deuterium nucleus, producing a tritium atom in the process. The tritium atom decays and in that process releases a gamma ray, which then collides with an electron. Cerenkov light is emitted and detected by photomultiplier tubes (shown in the background in this image) that line the inside of the SNO vessel.

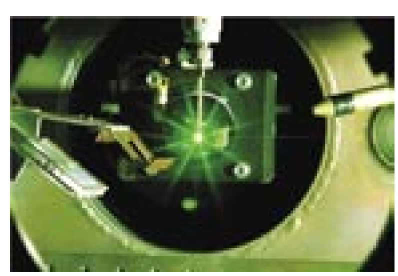
P-24: Plasma Physics

Cris Barnes, Group Leader
Carter Munson, Deputy Group Leader
Mike Ray, Administrative Deputy Group Leader

The Plasma Physics Group (P-24) has the mission "to nurture and use LANL's core discipline of experimental plasma science in basic and applied research to benefit LANL and the nation." The group applies an extensive knowledge of plasma physics, atomic physics, laser-matter interaction physics, dynamic material properties, laser and pulsed-power technology, and plasma diagnostic engineering and technology—all to study matter in the plasma state. P-24 addresses problems of national significance in inertial and magnetic fusion, laboratory plasma astrophysics, nuclear weapons stewardship, conventional defense, environmental management, and plasma-based advanced manufacturing (see http://www-p24.lanl.gov).

- The High-Energy-Density Physics and Fusion team conducts target-physics experimental campaigns at our own Trident laser, as well as the Omega laser at the Laboratory for Laser Energetics (LLE) (University of Rochester) and the Z pulsed-power facility at SNL. They study physics issues relevant to achieving inertial fusion and relevant to weapons physics and basic high-energy density physics, in particular, in the areas of laser-plasma instabilities, beryllium materials characterization, and the other properties of dynamic materials, fusion-burn diagnosis and capsule implosions, hydrodynamics and mix, and radiation flow and radiation hydrodynamics. The team is developing a variety of diagnostics and experiments for the National Ignition Facility (NIF).
- The Trident team performs experiments relevant to ICF, weapons physics, and basic high-energy-density physics while operating the Trident laser facility (a three-beam, 500-J green laser, now with 20-J sub-picosecond capability) (Figure 1). They also work on advances in laser and optical science.
- The Magnetic Fusion team conducts experiments emphasizing innovative confinement concepts and diagnostics development. The primary focus is a field-reversed-configuration experiment aimed at investigating magnetized target fusion. Other projects include collaborations at the Massachusetts Institute of Technology, Princeton University, and the University of Washington. There is a growing focus on plasma science and laboratory plasma astrophysics, including a reconnection-scaling experiment and a new flowing-magnetized-plasma experiment.
- The Applied Plasma Technologies team applies energetic non-equilibrium plasmas to environmentally conscious and industrially efficient processes, with emphasis on basic physics, commercial applications, weapons-stockpile surety, and homeland defense. The work includes studies on non-thermal atmospheric pressure plasmas and new applications such as plasma combustion and plasma aerodynamics.
- The Diagnostic, Engineering, and Operations team provides engineering and technical support for many of the projects in the group. In addition to supporting experiments and diagnostics used at Omega, Trident, and soon NIF, the team designs, engineers, builds, and maintains diagnostic systems such

Figure 1. View inside the Trident laser laboratory target chamber. Targets may be illuminated with up to several hundred joules of energy in pulses ranging from picoseconds to microseconds in length.



as x-ray framing cameras, neutron imagers, gas Cerenkov burn-history diagnostics, streaked optical pyrometers, and target positioners. The team also operates a world-class research machine shop and provides photographic laboratory and digitization support.

- Finally, the Administrative team provides secretarial, operational, safety and security, computational and network, and general management support for the group.

In FY 2003, the group employed 81.5 full-time equivalent people on an $18 million budget. The group typically has over 100 people working during the summer months, including a student population of 25 during last summer. To attract and educate these students, challenge and inspire our staff, and provide connections to visiting scientists, we created a more formal Plasma Physics Summer School (http://wsx.lanl.gov/RSX/summer-school/Summer_school_homeage.htm) with twenty-one lectures and seminars. The group maintains a vital post-doctoral researcher program with nine postdocs at present, including a Reines Fellow and a Director's Funded postdoc. The postdoc program has contributed to a demographic staff profile that is nearly flat with age. Twenty percent of the postdocs and staff are foreign nationals as the group maintains a commitment to hiring the best scientific talent to meet its mission. The group recognizes that its future scientific work will involve ever more complicated measurements on complicated experiments. We thus have a significant and growing component of engineering staff in the group and are actively recruiting and hiring a larger proportion of technicians for the group, mostly at the entry level to be trained over the next decade by our outstanding corps of senior technicians.

P-24 is located at TA-35 in primarily six buildings covering a little over 53,000 sq ft. This area includes experimental laboratories for the Trident laser, the FRX-L magnetized-target-fusion experiment (Figure 2), the flowing-magnetized-plasma experiment, the reconnection studies experiment, the Applied Plasma Technologies Laboratory, several laboratories for diagnostic development and checkout (i.e., x-ray sources, materials diagnostics, two laser laboratories, and an optical-diagnostic checkout facility), the machine shop and photo laboratories, and smaller laboratories associated with many of the technicians. Because P-24 is located near the Materials Science Division Target Fabrication Facility and major collaborators for our high-energy-density physics and fusion work and has plenty of parking, the group is well situated for its laboratory infrastructure.

P-24 has strategic objectives in high-energy-density physics, with specific plans to grow LANL's involvement in NIF and in the science campaigns aimed at studying primaries (Campaign 1, or "Boost") and secondaries (Campaign 4). Strategic objectives also include high-intensity short-pulse (sub-picosecond) laser-matter interactions, the properties of materials under dynamic conditions, innovative fusion confinement concepts such as magnetized target fusion, development of laboratory plasma astrophysics, and new applications of non-thermal plasmas. All of these are exciting fields of physics with strong growth potential that can contribute to achieving our vision "to be recognized as a world-leading organization for plasma physics and fusion science and technology, a home of trusted expertise, a place of choice for people to work and visit, and a partner of choice for sponsors and collaborators."

Figure 2. Members of the FRX-L magnetized-target-fusion experimental team, standing behind the collector plate between the main capacitor bank (right) and the field-reversed theta pinch (left).

P-25: Subatomic Physics

Martin Cooper, Group Leader
Mikkel Johnson, Geoffrey Mills, Acting Deputy Group Leaders

The Subatomic Physics Group (P-25) was created in 1994 as part of a reorganization of P Division initiated by former P Division Leader Peter Barnes. The scientific staff of P-25 was formed from P-2 (Medium-Energy Physics) and the research groups MP-4 and MP-10 of the Medium-Energy Physics (MP) Division. The common thread uniting these groups was leadership in investigations of issues of subatomic physics that could be addressed in experiments at a number of accelerator facilities, including the Los Alamos Meson Physics Facility (LAMPF), currently known as the Los Alamos Neutron Science Center; the Fermi National Accelerator Laboratory (FNAL); the European Organization for Nuclear Research (CERN); and the Superconducting Super Collider (SSC). Because of the diverse physics being conducted in MP-4, MP-10, and P-2 and tight funding at the time, it was clear that the group would have to undergo a consolidation of its research priorities. John McClelland (now Deputy Director for Experimental Physics in the Weapons Physics Directorate at LANL) was the first group leader of P-25, and under his direction the research priorities were narrowed and about half of the group redefined its area of focus.

A number of the programs and projects described below are featured in this report. As noted, P-25 staff members often participate in large-scale collaborations that involve physicists from universities and institutions from around the world, and the group contributes to or leads experiments at a variety of facilities. The intellectual atmosphere in the group is enhanced by local workshops and students who come to participate in the research and by a small theory group that brings in numerous theory visitors involved in research areas of interest to the group.

New themes in P-25 became studies of fundamental issues of the Standard Model (the primary focus) and the search for a basis for stronger collaborations between fundamental physics and the weapons community. The group's current experimental activities emerged during the mid 1990s. Neutrino physics, with an emphasis on searches for neutrino oscillations, now focuses on the MiniBooNE experiment at FNAL (Figure 1). This experiment is the first phase of the larger Booster Neutrino Experiment (BooNE) that will definitively test results from the Liquid Scintillator Neutrino Detector (LSND) (which took data from 1993-1998 at LAMPF) to confirm neutrino oscillations and will precisely measure the oscillation parameters. This experiment will also test CP (charge conjugation/ parity transformation) and CPT (the combined operation of charge conjugation, parity inversion, and time reversal) violation in the lepton sector and will explore new methods of detecting "double beta decay" of nuclei to further understand the nature of the neutrino. In addition to neutrino studies, P-25 is involved in the relativistic-heavy-ion investigations currently under way at the Relativistic Heavy

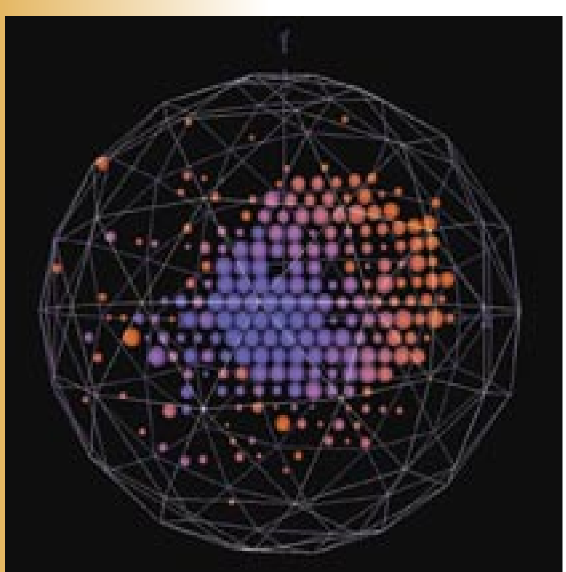


Figure 1. The colors in this typical MiniBooNE neutrino event relate to elapsed time—the blue represents early photomultiplier-tube (PMT) hits and the orange represents later PMT hits. In this particular data event, there were fewer than six veto hits and over 200 tank hits.

Ion Collider (RHIC) at BNL. The goal of these investigations is to create and to study the exotic properties of a primordial quark-gluon plasma in a laboratory. This activity was an outgrowth of the successful relativistic-heavy-ion program at CERN, which was under way in P Division at the time P-25 was formed, and the joint research program in P and MP Divisions to study Drell-Yan and charmonium physics at FNAL.

Another theme in P-25 involves neutron physics at LANSCE, which is aimed at studying symmetry violation and searching for physics beyond the Standard Model. Members of P-25 are currently searching for the EDM of the neutron, which was an outgrowth of early work in fundamental symmetries. Proton radiography—a technology that images dynamic variations of macroscopic objects over small time intervals with millimeter spatial resolution—is a new activity that was inspired by P-25's familiarity with accelerator physics and its understanding of advanced detectors for imaging and handling high data rates (Figure 2). (Application of the same underlying principles is also contributing new ideas for homeland defense.) P-25's pRad program has three goals: (1) to demonstrate that high-energy pRad is a suitable technology for meeting the goals established for the advanced radiography program, (2) to advance the technology of charged-particle radiography, and (3) to apply 800-MeV pRad to the needs of the science-based stockpile stewardship program. Members of the pRad team recently commissioned a new radiography system that images dynamic events with an order of magnitude higher spatial resolution and another system that significantly improves the sensitivity to thin objects. A prototype electron-radiography system, designed by P-25 and constructed at the Idaho Accelerator Center (IAC), was used to continue investigations in the use of electrons as direct probes for static and dynamic radiography of thin systems. Other projects and activities are listed below:

- The development of a silicon vertex detector upgrade for the PHENIX (Pioneering High-Energy Nuclear Interaction Experiment) detector at RHIC enhances the capability for studying the gluon distributions in colliding nuclei and the early evolution of the formation of the quark-gluon plasma by directly detecting heavy quark decays.
- The first measurement of the Drell-Yan cross section in p-p collisions over a broad kinematic range has been made, and the most extensive study of p-d collisions uncovered a pion cloud-like feature of the nucleon.
- In an investigation of spin physics at the RHIC, members of P-25 successfully measured J/Ψ production with the newly installed south muon detector from the first polarized p-p collisions at RHIC.
- P-25 is collaborating with P-23 to provide better sources of UCNs—neutrons that can be trapped by ordinary materials and then used for a variety of experiments probing fundamental quantities with high precision.
- In the first test of an experiment aimed at improving the limit on the EDM of the neutron, the properties of dilute mixtures of ^{3}He in superfluid ^{4}He and a measurement of the diffusion coefficient for ^{3}He were made—this work led to a Laboratory Distinguished Performance Award for the UCN team.
- The HiRes experiment at the Dugway Proving Grounds in Utah is measuring UHECRs ($> 10^{18}$ eV) with detectors sensitive to the air fluorescence of showers caused by cosmic rays entering the atmosphere—HiRes will ultimately help researchers understand the types of mechanisms that can produce such energies.
- Recent theoretical activity in P-25 has focused on parity violation in chaotic nuclei, deep inelastic scattering and Drell-Yan reactions as a means to explore quark propagation in nuclei, quantum chromodynamics (QCD) at finite temperatures, and phase transitions in the early universe.
- P-25 is making numerous contributions to homeland defense based on novel applications

Figure 2. Members of P-25 performing calibration tasks before a pRad shot.

of nuclear physics techniques, including muon radiography and Compton-gamma-ray imaging—both of which are high-sensitivity detection techniques that could aid in the surveillance for contraband special nuclear material—and VLAND (Very Large Area Neutron Detector), which applies neutrino detector technology to the identification of special nuclear materials.

- P-25 group members continue to be active in education and outreach activities, both as participants in programs sponsored by LANL, whereby high school, undergraduate, and graduate students work on projects within the group, and as individual citizens who volunteer their time for various activities (visit http://users.hubwest.com/hubert/mrscience/science1.html for information for an example of this activity).

The cutting-edge science described here not only advances fundamental knowledge and spawns creative ideas for new technology, but it also is a key ingredient of LANL's ability to attract and retain the high-caliber talent it needs to fulfill its mission of national security.

Physics Division Interactions with Industry and Technology Transfer

D.M. Coates
(Physics Division Office)

Commensurate with the fact that the DOE has made technology transfer a priority for its national laboratories, P Division is aggressively pursuing partnerships with industry to transfer Division-invented technologies into the private sector. Additionally, P Division's efforts are complementary to a recent request by Laboratory Director Pete Nanos that we leverage industrial partnerships to make critical performance improvements for executing Divisional business plans. It is gratifying that the range of technologies that P Division is grooming for transfer to industry is quite broad. Described below are some of these technologies.

Technology Highlights

Muon radiography for detection of clandestine nuclear material. Muons, elementary particles that shower down on the earth, hold promise as a sensitive means of detecting nuclear materials being smuggled into the country. These charged subatomic particles are produced when cosmic rays strike air molecules in the upper atmosphere. A team of LANL scientists has developed a way to use muons to detect terrorist attempts to smuggle uranium or plutonium into the country. The technique, known as muon radiography (Figure 1), also detects lead and tungsten, which could be used to shield the gamma rays emitted by nuclear materials. Muon radiography tracks the scattering angles of the particles as they pass through material. High-Z materials produce much more muon scattering than do lower-Z materials. Particle detectors above and below a vehicle or container record each muon's path before and after the muon passes through the cargo. A change in the muon's trajectory means that the muon has been scattered by the cargo. Using the path information and muon-scattering theory, a computer program then constructs a three-dimensional image of the cargo's dense, high-Z objects. We are in the process of transferring information to a number of companies interested in commercializing the technology. In addition to outside companies, the Department of Homeland Security is highly interested in the technology for national security reasons. A patent on the technology is being drafted by the DOE.

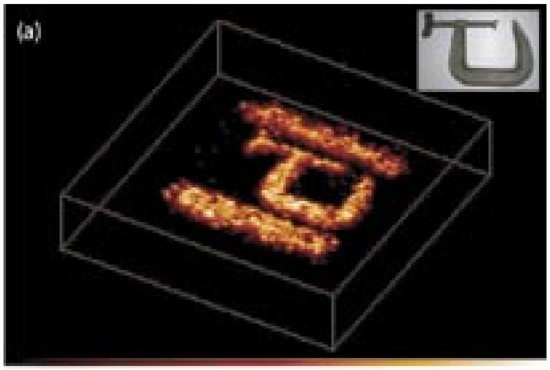


Figure 1. Experimentally produced cosmic-ray muon radiographs of (a) a steel c-clamp and (b) the acronym "LANL" constructed from 1-in.-lead stock. The bar-like features visible on either side of the images result from steel beams used to support a plastic object platform. This work was carried out at LANSCE.

Advanced combustion technologies using atmospheric plasmas. Fuels are broken down (cracked) into smaller molecular fragments, boosted into reactive excited states, or made into "free-radicals," before combustion with a highly efficient plasma technology. This technology allows for very "lean-burn" modes of combustion to be used for reduction of NO_x—a highly desirable feature of the technology. "Proof of principle" has been demonstrated in experiments using propane as the fuel in a specially made plasma chamber/burner

Figure 2. Illustration of the coaxial dielectric-barrier, non-thermal plasma reactor used in the combustion enhancement studies. Figure 2(a) shows the propane air flame without plasma, and Figure 2(b) shows the more robust flame with plasma.

device (Figure 2). The technology has been advertised and information exchange is in progress at this time. Interested companies include two major auto manufacturers and a company that is exploring the concept for forming a new company around the technology. A number of patents have been filed on the technology and other uses, such as ozone generation for water treatment and the destruction of hazardous air pollutants, are being considered as another manifestation of the technology.

High-efficiency compact turbine engine. A unique turbine engine configuration that offers many potential improvements, including fuel efficiency, more compactness, and lower manufacturing costs, has been invented. The Advanced, Single-Rotor Turbine (ASRT) engine achieves these improvements through use of a new flow-path strategy that results in superior cooling of the critical turbine section. The ASRT channels intake air from the compressor through the hollow turbine blades on its way to the combustion chamber (Figure 3). This design cools the critical turbine section of the engine and allows the engine to operate at higher temperatures, thus using its fuel much more efficiently. Alternatively, it allows the engine to operate at current temperatures but be constructed from cheaper, lower-temperature alloys. The one-piece compressor/turbine reduces engine complexity and weight. We are working with DOE to explore the design and commercialize the engine. Two turbine companies are in negotiation with us for a CRADA (Cooperative Research and Development Agreement) to develop the concept. Although the ASRT engine can have impact in aircraft auxiliary power units, in distributed power strategies in the home and small business, and as an aircraft thrust/propulsion unit, its first application may be for the U.S. Army as a battlefield power-generation unit. The patent portfolio for the engine is growing beyond the first issued application with filings on turbo-machinery applications and improved combustor designs.

INFICOMM—Power-efficent wireless technologies for cell phones, telemetry, and rf identification. The growth of wireless may ultimately be limited by the dependence of cell phones on battery power. While battery technologies have advanced over the past decade to allow for much smaller telephones, typical "talk" times are currently limited to around

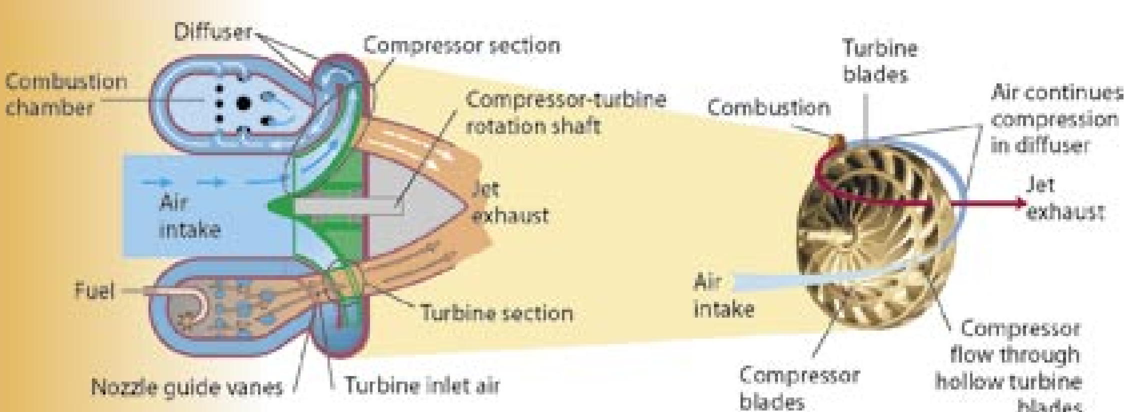


Figure 3. Composite drawing of the ASRT schematic and photo, showing how the ASRT operates. Air from the compressor section of the ASRT is channeled through the outer hollow turbine blades on the same rotor. The air, on its way to the combustion chamber, cools the turbine section allowing the engine to operate at higher temperatures. The fuel efficiency is increased in this case.

2 to 4 hours and "standby" times are from 20 to 40 hours. For many cell-phone users, the battery is insufficient for voice services and expanded wireless capabilities. Researchers at LANL have developed a wireless communications technology, known as INFICOMM, that provides expanded wireless voice and data applications via essentially unlimited battery life, eliminates potential health risks of rf energy, minimizes impact of battery disposal on the environment, and lowers cell-phone costs. This unique technology uses "modulated-reflection" technology (i.e., the reflection of rf energy provided by a tower's transmissions reflected off of the cell phone's antenna to carry the return half of the communication). This strategy thus reduces or eliminates the cell phone's need for battery power consumption for its transmissions back to a tower. The technology has broad applications in many areas, including cell phones, telemetry, and rf identification systems. We are working with Chevron-Texaco on a CRADA to explore the technology for sending sensor telemetry from down-hole to above ground. The patent portfolio has been growing and should include four patents with the originally issued patent.

KEYPATH—Using atmospheric turbulence to generate and exchange cryptographic keys. A new cryptographic-key-transmission technology for laser-through-air modes, known as KEYPATH, has recently been declassified and is being advertised to the communications industry. The technology uses a unique strategy for creating distinct key codes that cannot be intercepted by any known means and should be invaluable for sending the codes to satellites. We have recently opened dialog with companies on the technology, and initial responses to this new technology have been enthusiastic. A patent application on the technology is in draft. Members of P-22 are taking measurements over paths of varying lengths to demonstrate the effectiveness of the system.

Magnetocarcinotheropy. A magnetic-based method of detection and treatment of cancer has been invented and has been discussed with a wide range of companies. A patent has been issued on the technology. Although most companies are enthusiastic about the technology, delays in actually demonstrating "proof of principle" of the technology have caused companies to feel that the risk of jumping in as a partner is too high at this early stage of exploration. Hence, we will likely have to move the technology further before we lower the risk level to the point that companies will fund efforts around the technology.

Figure 4. Prototype robot guided by a new vision system invented by researchers at LANL.

Robotic vision using biological theoretical principles. Researchers at LANL have invented an exciting vision system derived from biological vision processes. The system, resulting from LANL expertise in electrical engineering, parallel processing, and computational neuroscience, demonstrated a novel approach to traditional problems in computer vision such as the "aperture" problem and motion disruptions that occur during a robot's steering operations. The vision system guided a prototype robot (Figure 4) around an unknown obstacle course in a fully autonomous configuration, in many ways surpassing the state of the art in conventional computer-vision techniques. The current system was implemented on a Linux cluster with future plans to move to a fully custom analog or digital hardware system. We are currently engaging the robotics industry to use our method in commercial products.

Electromagnetic geophysical research. Researchers at LANL are pursuing four distinct, yet electro-magnetically related, geophysical applications in cooperation with an industrial partner, Stolar Research Corporation. The first is a portable instrument that has been devised for detecting both dielectric and conductive buried landmines. The principle involved requires the interference between an incident electromagnetic wave, its ground-reflected component, and the scattered wave from the landmine. The sensor is a patch antenna whose impedance changes in the presence of the scattered wave. The second application is a ground-penetrating radar for coal mining. Coal-mine operations generally occur in stratified layers where avoiding cutting into rock layers beyond the coal-rock surface is important. A sensor placed in the cutting drum could measure the thickness of coal layers by detecting standing waves produced by a near discontinuity in the dielectric constant and conductivity of the two layers. A third geophysical application involves the development of magnetic-induction methods to locate and determine the depth of the subsurface line source of a magnetic field. The origin of the field may be self-generated or -induced by a surface transmitter. The latter requires the generation of a low-frequency electromagnetic wave that scatters off the structure (such as a tunnel), part of which returns to the surface. The weak-scattered wave is generally in the background noise but may be detected by measuring the field gradient (i.e., the spatial rate of change), thereby greatly increasing the signal-to-noise ratio. Both detection and depth result from the sensor output. The fourth geophysical application involves tunnel communications. Radio communications in tunnels generally are very inefficient because of factors such as mode interference, waveguide cutoff, and wall attenuation. Success has been achieved by using low-frequency surface waves coupled into parallel tunnel conductors by means of a transmitter driving a magnetic dipole antenna. The surface waves consist of inhomogeneous transverse electromagnetic waves that are guided by any conductor parallel to the tunnel walls. Reception is achieved by a similar small-loop magnetic dipole feeding a radio receiver. The primary application of this method of tunnel communications is for mine safety with special emphasis on communication during fires.

Conclusion

The range of technologies that P Division is pursuing with industry is indeed broad and spans diverse arenas, including the prevention of nuclear-weapons entry into the U.S., new communications methodologies, energy/propulsion systems, and advanced cancer detection and treatment technologies. We believe that P Division is leading the way in meeting the LANL objective of creating and transferring important and commercially exciting technologies to the industrial sector. Such technologies will aid in giving the U.S. economy the leading-edge technical advantage it needs to remain in world leadership.